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A small BF_3 ionization chamber for absolute neutron measurements

By Karl-Erik Larsson and C. Taylor

With 13 figures in the text

I. Introduction

Several methods of measuring the total flux of neutrons from a source of neutrons have been described, [1, 2, 3, 4], of which that of Bauer et al. is perhaps the most direct. This method makes use of a small ionization chamber filled with BF_3 gas, and it is necessary that 100 % of the nuclear reactions $B(n,\alpha)Li$ occurring in its sensitive volume should be recorded. If electron collection is used, the position of each ionization track in the chamber governs the size of the resulting voltage pulse, and it is therefore useful to calculate the proportionate number of very small pulses, as these will be obscured by amplifier noise. Such a calculation is given in § II below. In § III the experimental performance of a small chamber is compared with the theory, and in § IV an amplifier and sonde mounting for use with the chamber are described.

II. Theoretical deduction of bias curve

a. General

An ionization chamber may be used with either electron or ion collection. The choice is made by selection of the amplifier time constants, long time constants corresponding to ion collection. The use of such time constants gives much trouble (microphonics, alternating current pick-up, piling up at higher counting rates, etc.) and it is of considerable advantage to use short time constants, which means that only the fast part of the pulse, occurring while the electrons are swept from the chamber, is used. But if the chamber is used in this way, it is necessary to know whether the bias curve has a plateau, and, if it has not, in what way the curve should be extrapolated down through noise to zero bias. The calculations given below were made in order to find the form of the low-amplitude end of this curve, which must be known if the chamber is to be used for absolute counting, and is useful to know even for relative counting.

It is possible to calculate the form of the bias curve for the electron collecting chamber, if the charge collected on the positive electrode is known as a function of the direction of movement of the Li- and α-particles from the reaction centre in the field between the electrodes. From simple energy considerations a formula can be found for the collected negative charge Q, which has been done by ROSSI and STAUB [5]. If V_0 is the potential difference between the electrodes, $V_i(0)$ the potential at the point where the i:th ion pair was created, N_0 the number of created ion pairs, and e the electronic charge, then

$$Q = -\frac{e}{V_0}\sum_{i=1}^{N_0}[V_i(0) - V_0]. \tag{1}$$

In deriving this formula it has been assumed that

1. the diffusion of ions is negligeable,
2. there is no recombination of ions,
3. there is no electron capture in the gas, and
4. there is only a small current through the grid leak resistance at the amplifier input, so that V_0 may be taken as constant. These points will be discussed later.

It is apparent from equation 1 that the voltage pulse height will be directly proportional to the potentials through which the electrons fall. In order that as many pulses should be as large as possible it is therefore of advantage to use a cylindrical chamber with central electrode positive, this electrode having as small a radius as practicable in order to concentrate the greater part of the potential drop in a small volume close to its surface. It may be noted that for large high-pressure chambers such a design is not suitable, as the weak field in most of the chamber will allow loss of charge by recombination, and the mechanically weak central electrode may give troublesome microphonics.

b. Calculation of bias curve, for a long cylindrical chamber

In calculating the pulse spectrum from equ. 1 two cases will be considered:
1. when the pressure of BF_3 in the chamber is very high, and
2. when the pressure is low.

1. High gas pressure. The centre of a reaction B(n,α)Li may occur with equal probability at any point in the chamber. The pressure is assumed to be so high that the ranges of the particles are negligeable, i.e. all the ionization caused by a nuclear disintegration occurs within a very small volume. Then from equ. 1,

$$Q = eN_0\left[1 - \frac{V(r)}{V_0}\right] \tag{2}$$

where $V(r)$ is the potential at distance r from the axis of the chamber. But

$$V(r) = V_0\frac{\log\frac{r}{b}}{\log\frac{a}{b}} \tag{3}$$

where a = radius of central wire, and
b = radius of cylinder.

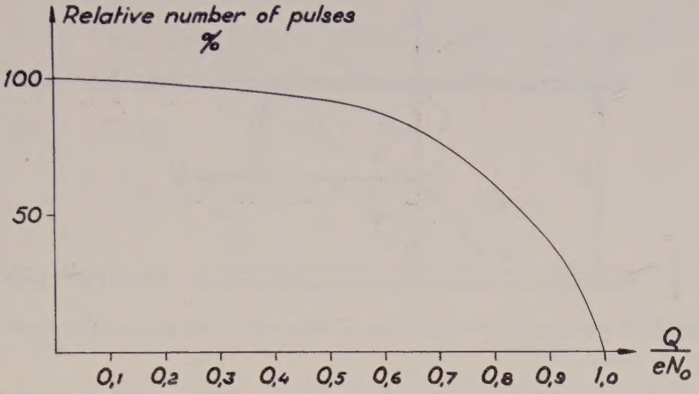

Fig. 1. Bias curve calculated for the case when the ionizing particles have vanishingly small range.

The charge collected is then

$$Q = eN_0\left(1 - \frac{\log\frac{r}{b}}{\log\frac{a}{b}}\right). \tag{4}$$

Let ϱ be the number of nuclear reactions per unit volume. Then the number of reactions n_r, which give pulses bigger than a certain size corresponding to a collected charge $Q(r)$, is

$$n_r = \varrho\pi(b^2 - r^2) \tag{5}$$

per unit length of the chamber.

If r is eliminated between (4) and (5) there follows

$$n_r = \varrho\pi b^2\left[1 - e^{-2\left(1-\frac{Q(r)}{eN_0}\right)\log\frac{b}{a}}\right]. \tag{6}$$

Now by its definition

$$n = \frac{n_r}{\varrho\pi(b^2 - a^2)} = \frac{b^2}{(b^2 - a^2)}\left[1 - \left(\frac{b}{a}\right)^{-2\left(1-\frac{Q(r)}{eN_0}\right)}\right] \tag{6'}$$

is the equation for the bias curve, when n is the relative number of pulses bigger than a certain size $\frac{Q}{eN_0}$. The curve for $\frac{b}{a} = 12$ is given in Fig. 1.

2. Low gas pressure. In this case the finite range of the Li- and α-particles must be taken into consideration. All directions of the particle tracks are assumed to be equally probable. The reaction centre O (Fig. 2) is chosen as the origin of a coordinate system (x, y, z) so that the xy-plane is a tangent plane

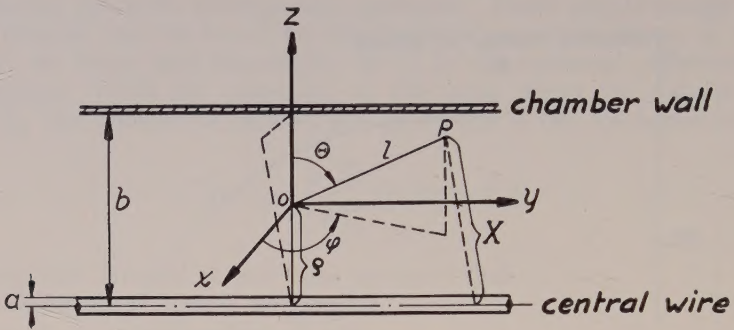

Fig. 2. Orientation of axes for calculation of bias curve when particles have finite ranges.

to the equipotential surface through O. The z-axis passes through the central axis of the chamber and the y-axis is parallel to it. One of the product particles (Li nucleus or α-particle) moves along OP. The perpendicular distance X to the central wire from a point P at distance l from O along this track is determined by

$$X^2 = x^2 + (z + \varrho)^2 \tag{8}$$

where ϱ is the distance from the central axis to the reaction centre O. In polar coordinates with origin at O

$$X^2 = l^2 (\sin^2 \Theta \cos^2 \varphi + \cos^2 \Theta) + 2 \varrho l \cos \Theta + \varrho^2. \tag{9}$$

Equation 1 gives for the charge

$$Q = e N(l) - \frac{e}{V_0} \int V(l)\, d N(l). \tag{10}$$

To make the calculation practicable it is assumed that the ionization along a track is constant.

If a number N_0 of ion pairs are created along a track of length R_0, it follows that

$$N(l) = \frac{N_0}{R_0} l. \tag{11}$$

If now $V(l)$ in equ. 10 is replaced by its actual value, the expression for the charge collected is

$$Q = \frac{e N_0}{R_0} l_1 - \frac{e N_0}{R_0 \log \frac{a}{b}} \int_0^{l_1} \log \frac{X(l)}{b}\, dl. \tag{12}$$

The upper limit l_1 of the integral is determined by

1. $l_1 = R_0$ if $X(R_0) \leq b$

and 2. $l_1 < R_0$ if $X(R_0) > b$.

In this last case l_1 is determined by $X(l_1) = b$ which gives

$$l_1 = \frac{\sqrt{b^2 \cos^2 \Theta + (b^2 - \varrho^2) \sin^2 \Theta \cos^2 \varphi} - \varrho \cos \Theta}{\sin^2 \Theta \cos^2 \varphi + \cos^2 \Theta}. \tag{13}$$

Integration gives for (12)

$$Q = \frac{e N_0}{R_0} \Bigg[l_1 + \frac{1}{\log \frac{b}{a}} \Bigg\{ \frac{l_1}{2} \log \frac{A l_1^2 + 2 \varrho l_1 \cos \Theta + \varrho^2}{b_2} - l_1 +$$

$$+ \frac{\varrho \cos \Theta}{2A} \log \frac{A l_1^2 + 2 \varrho l_1 \cos \Theta + \varrho^2}{\varrho^2} + \frac{\varrho \sin \Theta \cos \varphi}{A} \operatorname{arctg} \frac{l_1 \sin \Theta \cos \varphi}{l_1 \cos \Theta + \varrho} \Bigg\} \Bigg] \tag{14}$$

where $A = \sin^2 \Theta \cos^2 \varphi + \cos^2 \Theta$.

From equ. (13) and (14) the collected charge may be calculated for an arbitrary direction of the tracks of the Li- and α-particles. These particles, however, leave O in opposite directions and with the reaction energy divided in the ratio 4:7. In simplified form equ. 14 may be written

$$Q = \frac{e N_0}{R_0} f(\varrho, \Theta, \varphi) \tag{14'}$$

where l is eliminated between (13) and (14). For the Li- and α-particles (14′) is written

$$\left. \begin{aligned} Q_{\mathrm{Li}} &= \frac{e N_{0_{\mathrm{Li}}}}{R_{0_{\mathrm{Li}}}} f_{\mathrm{Li}}(\varrho, \Theta, \varphi) \\ Q_\alpha &= \frac{e N_{0_\alpha}}{R_{0_\alpha}} f_\alpha(\varrho, \Theta, \varphi) \end{aligned} \right\}. \tag{15}$$

The sum of these charges is the total collected charge. Within the small energy interval between the Li- and α-particles the ranges may be assumed proportional to the energies, from which follows

$$Q_{\mathrm{total}} = Q_{\mathrm{Li}} + Q_\alpha = \frac{e N_0}{R_0} (f_{\mathrm{Li}} + f_\alpha) \tag{16}$$

or

$$\frac{Q}{e N_0} = \psi(\varrho, \Theta, \varphi) \tag{17}$$

where N_0 is the total number of ion pairs and R_0 is the sum of the ranges of the particles.

The calculation of the pulse spectrum could now be made from equation 17 in a statistical way. The probability $S\left(\frac{Q}{e N_0}\right)$ of finding a value of collected charge Q between Q and $Q + dQ$ is proportional to the solid angle $d\omega = \sin \Theta \, d\Theta \, d\varphi$

in which the tracks lie, radiating from their reaction centre in $d\varrho$ at distance ϱ from the central axis. The total probability $S\left(\frac{Q}{eN_0}\right)$ is found by integration over the whole volume of the chamber of the expression

$$S\left(\frac{Q}{eN_0}\right) = \text{const.} \int\int\int \varrho\, d\varrho\, d\varphi \sin\Theta\, d\Theta .$$

In making this integration the values of ϱ, φ and Θ are determined by equation 17. The calculation can be made graphically, a great number of representative tracks being selected throughout the sensitive volume.

These tracks are chosen in the following way. The distance between the cylinder wall and the central electrode is divided up into a great number of equidistant cylindrical surfaces, which correspond to equidistant values of ϱ. Then the angle φ is given a series of equally spaced values between O and 2π. These values of ϱ and φ are chosen equidistant because every point in the chamber has the same probability of coinciding with the reaction centre and because all directions of the tracks occur equally often. With these selected values of ϱ and φ, $\frac{Q}{eN_0} = \psi$ becomes a function of Θ only. From equation 17, $\frac{Q}{eN_0}$ is then calculated as a function of Θ for all combinations of the selected values of ϱ and φ. The result is a family of curves $\frac{Q}{eN_0} = f(\Theta)$. In the $\varrho - \varphi$ plane small areas $d\varrho\, d\varphi$ around every pair of values ϱ, φ are considered. $d\varrho$ and $d\varphi$ are kept constant. In the $\frac{Q}{eN_0} - \Theta$ plane a constant $d\left(\frac{Q}{eN_0}\right)$ is taken which moves along the $\frac{Q}{eN_0}$-axis, and the corresponding values of Θ and $\Delta\Theta$, found from the curves $\frac{Q}{eN_0} = f(\Theta)$, are read along the Θ-axis. The probability $S\left(\frac{Q}{eN_0}\right)$ of finding a value of Q in dQ can now be rewritten

$$S\left(\frac{Q}{eN_0}\right) = \text{const.} \sum_i \varrho_i \sum_k \sin\Theta_{ik}\, \Delta\Theta_{ik}. \tag{18}$$

The summation is first made over all $\sin\Theta_k$, Θ_k corresponding to a constant ϱ, and then all $\varrho_i \sum_k \sin\Theta_{ik}\, \Delta\Theta_{ik}$ are summed over all values of ϱ. As described above, the values of Θ_k and $\Delta\Theta_k$ are found from the curves $\frac{Q}{eN_0} = f(\Theta)$.

The calculation of the family of curves giving Q as a function of Θ is very laborious, involving computation with equation 14. Since only the general form of the bias curve was required, and in particular the form at low bias values, no more points were calculated than were necessary to estimate the form and extent of each $Q - \Theta$ curve. In this approximate way the differential pulse spectrum has been calculated for 10 values of ϱ between a and b, 24 values of φ between O and 2π, and for $d\left(\frac{Q}{eN_0}\right) = 0.05$.

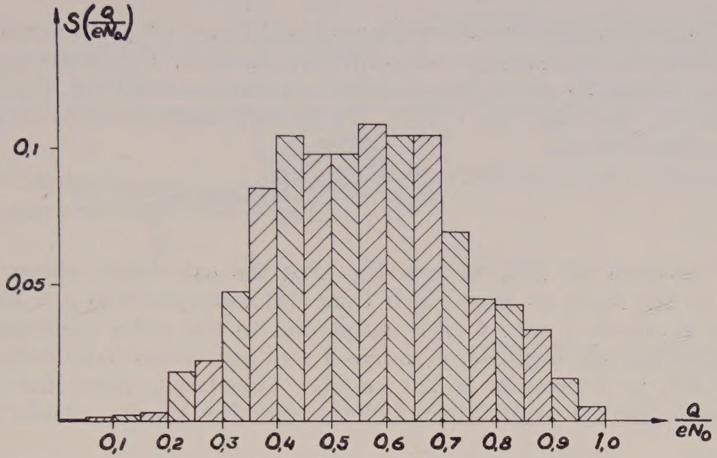

Fig. 3. Differential bias curve (theoretical).

$R_{0\alpha}$ was chosen to be 7.2 mm and $R_{0\,\mathrm{Li}}$ to be 4.2 mm, these values of the ranges corresponding to a pressure of about 300 mm Hg, as shown below. This pressure was taken because previous experimental work had shown that small chambers filled to such a pressure had plateau slopes less than when filled to higher pressures, presumably because the longer tracks have a smaller chance of lying entirely in a volume corresponding to small pulse height.

The chamber dimension constants were taken to be $a = 0.5$ mm and $b = 6$ mm.

In the course of the work it became clear that there would be very few small pulses, so that the slope of the bias curve in the region hidden by noise would be very nearly constant, and nearly equal to zero. To estimate this slope was the object of the investigation, and there was therefore no need to undertake a more exact calculation. The result for the differential curve is given in Fig. 3. From this it is easy to get the bias curve, by summation. This gives the curve shown in Fig. 4.

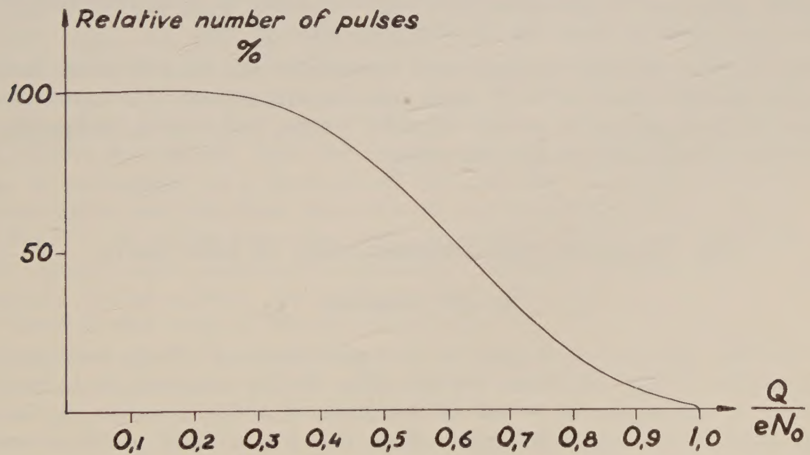

Fig. 4. Theoretical bias curve.

Bower, Bretscher and Gilbert [6] have found $R_{0\alpha} = 7.0 \pm 0.3$ mm and $R_{0\,\mathrm{Li}} = 4.3 \pm 0.2$ mm for standard air, using a Wilson chamber. Now the stopping power (s) for BF_3 relative to air is known from measurements of Dick, Falk-Vairant and Rossel [7], who find $s_{BF_3} = 2.15$. To convert ranges in air to ranges in BF_3 we can use the equation

$$R_{BF_3} = \frac{R_{\mathrm{air}}\,760}{2.15\,p} \tag{19}$$

where p = pressure of BF_3 in mm Hg. For the calculation above, R_{BF_3} was chosen to be the same as R_{air}, which from (19) corresponds to $p = 320$ mm Hg. The curves in figures 3 and 4 then correspond to the pulse spectrum and bias curve of a cylindrical chamber of radius 6 mm and central wire radius 0.5 mm, filled with BF_3 to a pressure of 320 mm Hg. Calculation shows that the correction for half-spherical ends is small if the chamber length exceeds five times its radius.

The following remarks may be made about the simplifying assumptions made to arrive at equation 1:

1. The diffusion effect of the ions may surely be neglected in a small chamber when electron collection is used, for, according to Rossi and Staub [5], p. 13, and according to measurements of Bistline [8], the drift velocity of electrons in BF_3 at the fields and gas pressures used here is of the order of 10^6–10^7 cm/sec. If the time constants t_r and t_c in the amplifier are of the order of 10^{-5}–10^{-6} sec., and the radius of the chamber is 6 mm, the time needed for the electron collection is certainly less than t_r and t_c, which are much less than the time necessary for the ions to move appreciably.

2. The recombination of ions in BF_3 has been measured by Dick et al. [7]. Their results show that at the fields and pressures considered here, recombination can be neglected.

3. Electron capture in the gas can be reduced very much by careful cleaning and out-gassing of the chamber before filling, and careful purification of the BF_3. The largest pulses measured experimentally were however somewhat smaller than expected, and work is going on to find the cause of this.

4. The current through the grid leak resistance, resulting from ionization, is very small, of the order of 10^{-12} amps, and, as this resistance is taken as $10^8\,\Omega$, the potential drop across it is less than 10^{-3} volts, and is thus negligeable compared to the voltage across the chamber.

III. Experimental measurement of bias curve

a. BF_3 chamber

A small BF_3 chamber of length 40 mm and diameter 12 mm was made from lead glass tube of wall thickness 0.5 mm (Fig. 5). By evaporation its inside was coated with a silver film of ~ 100 Å thickness, this film constituting the outer electrode carrying the negative high voltage. A 1 mm thick platinum wire was used as central electrode. Considerable trouble was spent on cleaning the cham-

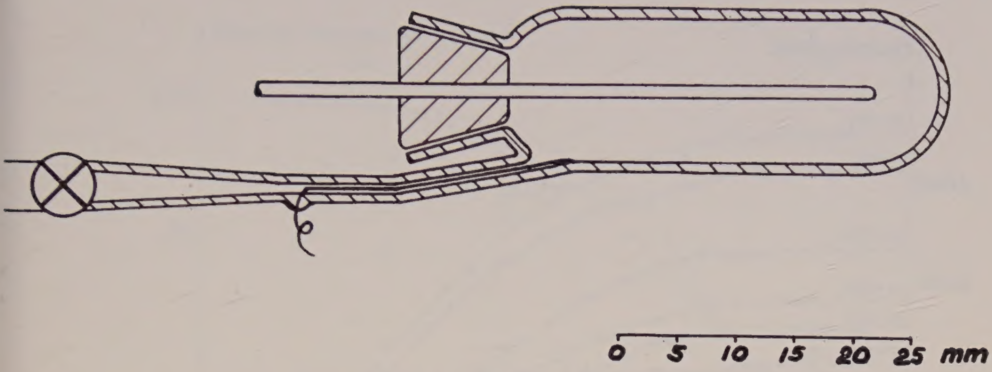

Fig. 5. Small boron chamber.

ber and on polishing the central electrode, which was brought into the chamber through a removable glass plug. This plug was finally sealed in place with Araldite type 1, after the chamber had been silvered. Araldite type 1 shows no sign of attack after several months of contact with BF_3, whereas cold-hardening Araldite type 101 becomes coloured after a few days.

For testing the chamber a paraffin geometry was constructed such that the chamber could easily be mounted in the same position after every filling. A 50 mC Ra-α-Be neutron source was used. To fill the chamber, commercial tank BF_3 was used, which was first purified by a method described by several investigators [12, 13, 14]. Most of the experimental trouble encountered arose during this last operation, as it was found that the form of the pulse spectrum was very sensitive to impurities in the gas.

b. Experimental results

After it had been pumped down to a pressure of less than 10^{-5} mm Hg the chamber was filled to a series of pressures from 180 to 755 mm Hg, and a bias curve was taken for each pressure. The voltage across the chamber was in all cases 850 volts. All the bias curves measured are given in Fig. 6. As will be seen from this all the curves have a linear part, which becomes longer with rising pressure. On the other hand the slope of this plateau becomes greater at higher pressures, which well agrees with the theory (see Figures 1 and 4).

In § II:b it was shown, that the ranges assumed to calculate the bias curve in Fig. 4 correspond to a pressure of 320 mm Hg. Comparison between this calculated curve and the bias curve found experimentally shows a good agreement (Fig 7). It might seem that the assumption of constant ionization along a track would cause considerable deviations between the theoretically and experimentally found curves. An explanation of the good agreement is probably to be found in the work of Bower, Bretscher and Gilbert [6] cited above; according to their work the ionization of the Li-nucleus is greatest near the reaction centre, but decreases rapidly with distance from this centre, while the more energetic α-particles give an ionization distribution corresponding to the usual Bragg curve form. Thus there is a tendency for charge lost when an α-particle strikes the wall to be made up when it is the Li-nucleus that is so stopped,

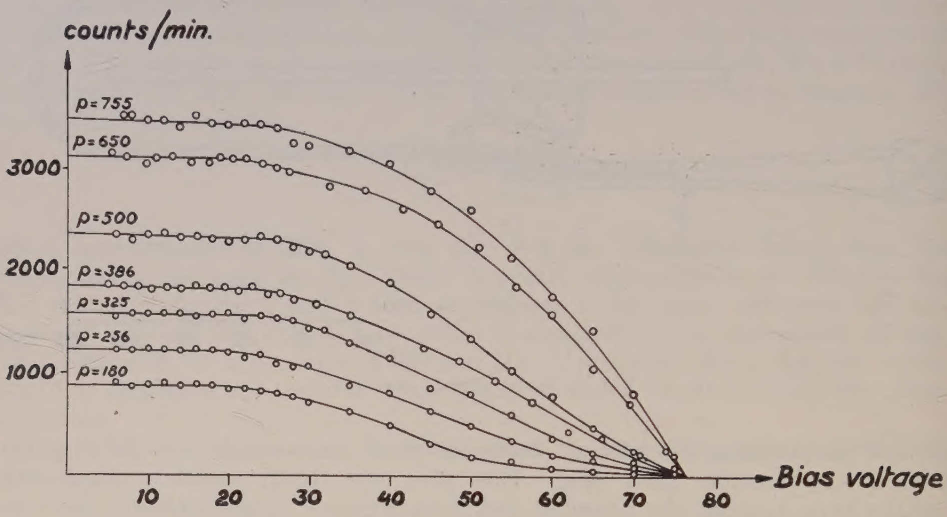

Fig. 6. Set of bias curves measured at different pressures.

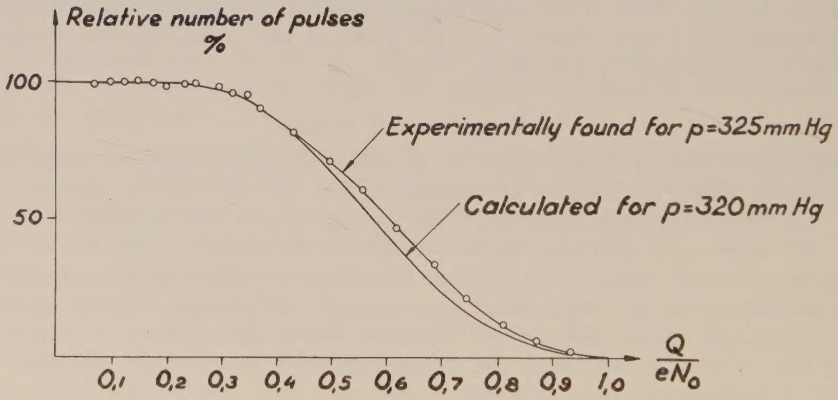

Fig. 7. Comparison of theoretical with measured bias curve.

and on the average this tends to act as if the ionization were constant along the tracks.

In Fig. 8 is shown how the curve found experimentally for $p = 755$ mm Hg tends towards that calculated theoretically for very short ranges of the particles. At low bias values the curves have the same slope, but at higher values the effect of the finite ranges begins to be appreciable.

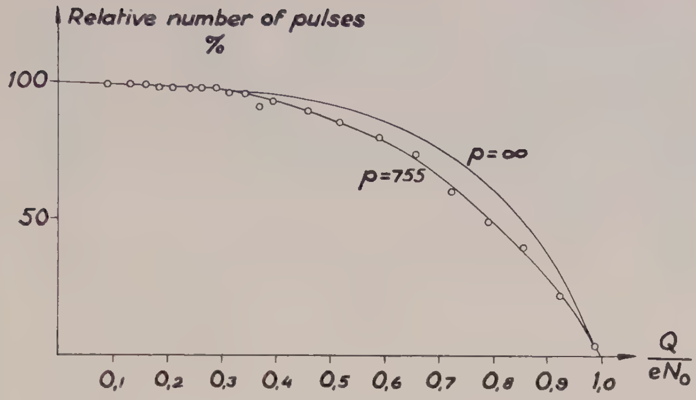

Fig. 8. Comparison of theoretical with measured bias curve at high pressure.

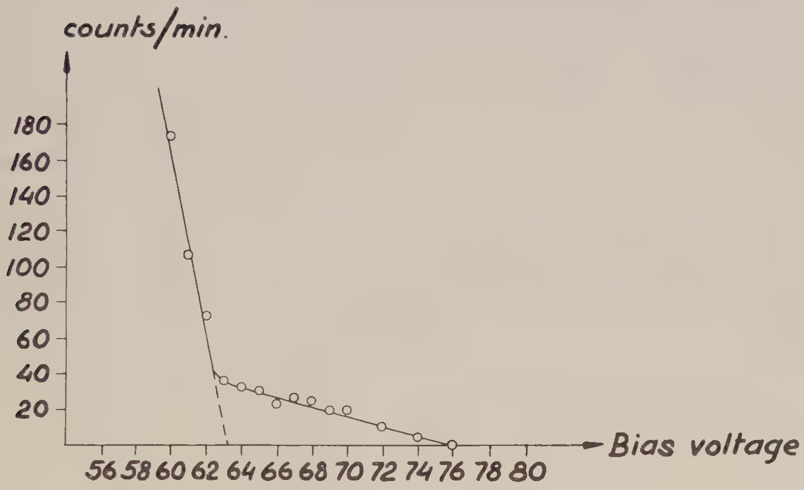

Fig. 9. Top end of bias curve, showing tail of curve due to B(n,α)Li reactions which result in the ground state of Lithium nuclei.

The reaction B(n,α)Li may take place in two different ways:

$$B^{10} + n^1 \begin{array}{l} \nearrow Li^{7*} + \alpha^4 + 2.31 \text{ MeV} \\ \searrow Li^7 + \alpha^4 + 2.79 \text{ MeV}, \end{array}$$

where the excited state occurs in 90 % and the ground state in 10 % of the disintegrations. The bias curves should therefore not stop at a bias voltage corresponding to 2.31 MeV, but some pulses should be counted corresponding to energies up to 2.79 MeV. Fig. 9 shows in detail the upper end of a bias curve

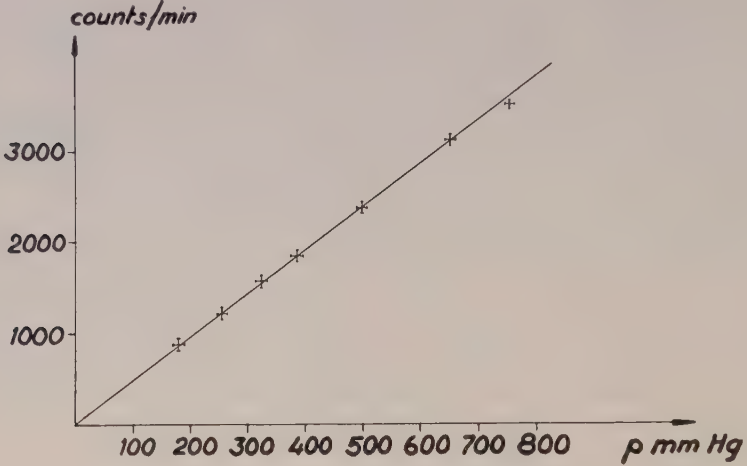

Fig. 10. Plot of counting rate against pressure.

found for $p = 700$ mm Hg. The steep part of this curve corresponds to the end of a curve similar to that in Fig. 8, followed by a similar spectrum of less numerous but larger pulses. The ratio between the two energies found from the diagram is 0.83 which agrees well with values given in the literature. The scale of Fig. 8 differs from that of the other bias curves, because a different paraffin geometry was used in making this measurement.

It is possible that some BF_3 may be absorbed on the chamber walls, or form chemical compounds with the materials from which the chamber is constructed. If this is the case, the number of boron nuclei in the sensitive volume of the chamber cannot be calculated from a knowledge of the pressure to which it is filled, and a correction must be made if the chamber is to be used for absolute measurements. To investigate this the chamber was filled with argon to a pressure of 650 mm Hg. When it was exposed to the same neutron flux as was used in the measurement of the curves in Fig. 6, the counting rate was 15 counts per minute at a bias setting of 5 volts, diminishing rapidly with bias voltage. The same rate was found after filling to another argon pressure, so this correction may be taken as constant (see also [1]).

Apart from this correction, the counting rate should be directly proportional to the pressure in the chamber. This fact was used to determine the pressure in the chamber after it had been sealed off. The counting rates obtained by extrapolating the bias curves down to zero bias were found for seven different pressures, the results being as shown in Fig. 10. The chamber was then filled to 439 mm Hg, and sealed off. Another bias curve was then taken, and the extrapolated zero-bias counting rate was found to lie close to the value expected from a consideration of Fig. 10. The BF_3 had been frozen down in the chamber during the sealing-off process, and this last counting-rate measurement was made to ensure that the freezing down had been complete, and that the final pressure was the same as that read on the manometer, after correction for the small loss of volume in sealing off.

IV. Equipment for use with the chamber

a. Amplifier

The amplifier was made up of three cathode-coupled feedback loops ([9], Fig. 2.20 b, p. 60), giving a total voltage gain of 3 × 10^5. Pulse shaping was done by a delay line connected between the first two loops, and by an R–C circuit in the feedback path of the second loop, which determined the rise time. The clipping time t_c, given by the delay line, was 2 μs: the rise time t_r was 1.5 μs. This arrangement gave a sharply pointed output pulse, which has been shown to give a better signal-to-noise ratio than the more rounded pulse produced if a simple R–C circuit is used to determine the clipping time [10]. Calculation showed that the gain of such an amplifier does not depend critically upon the intrinsic rise time of the amplifier unless this is greater than about 0.2 t_r. There was thus no need to build a fast amplifier, and it was possible to design a circuit similar to the Los Alamos model 100, with valves working economically at low current through large anode loads. 6AK5 valves were used for the first two loops. Their heaters were connected in series and fed from a direct current supply, to avoid 50 c/s pickup in the early stages.

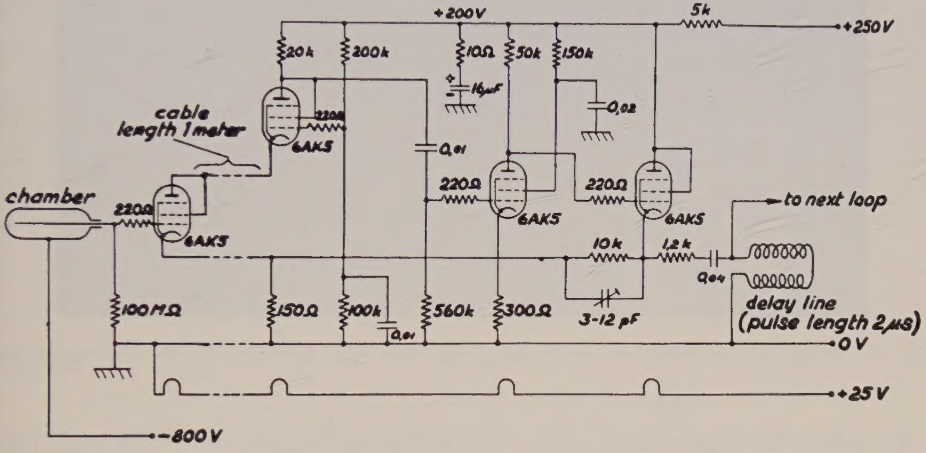

Fig. 11. Circuit of first loop of amplifier for use with the small BF_3 chamber.

As the amplifier was intended for the study of bias curves which were to be extrapolated to zero bias, some trouble was taken to secure as good a signal-to-noise ratio as possible. The input circuit (Fig. 11) consisted of two triode-connected 6AK5's working in cascade [10]: this circuit combines the advantage of a triode input stage (low shot noise) with that of the more usual but also more noisy pentode (low Miller effect). These two valves are included in the first feedback loop. The first triode is mounted close to the chamber, and is separated from the rest of the first loop by about one meter of cable. This gives no trouble, as both of the signal-carrying leads in this connection involve low-impedance points.

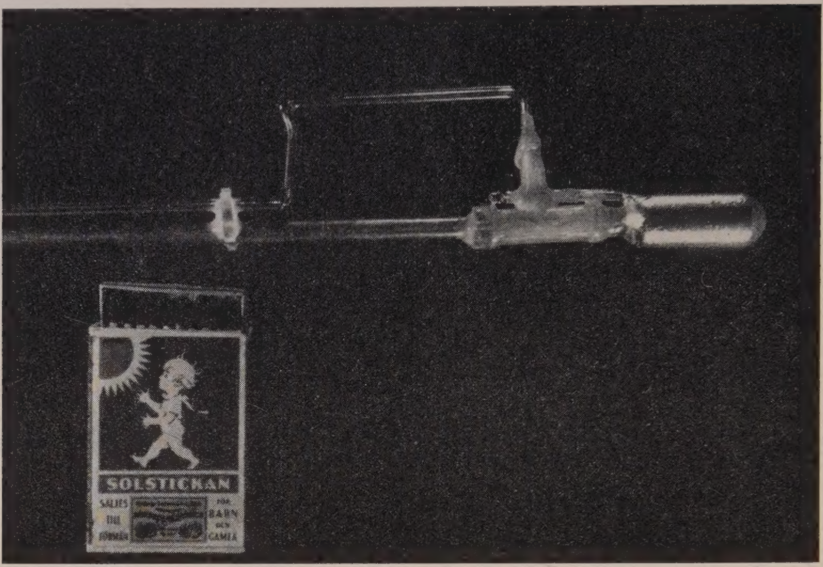

Fig. 12. Small BF_3 chamber on sonde mounting. The scale is shown by the the match box.

To select the input valve, about 100 6AK5 valves were tested: for each valve the noise at the amplifier output was rectified and its mean value measured. Apart from those that were faulty, these valves fell into two groups, one having about 30 % more noise than the other. The spread in each group was about 10 %: the worst valve had 1.6 times more noise than the best.

Each valve was also checked for microphonics by measuring the increase in its noise output when the test chassis was tapped by a standard electro-mechanical system. The valve finally selected was aged for three days at 12 mA anode current, anode voltage 120 V, and heater voltage 8 V. This decreased its noise output by 15 %, but this advantage was offset by a simultaneous fall of 5 % in mutual conductance.

It should be borne in mind that the signal-to-noise ratio of an input circuit depends on many factors: band-width, input capacity, working conditions of the valves, etc. [11]. With so many variables it is difficult to find a convenient way of testing many valves. The working conditions of the input stage shown in Fig. 11 were chosen, by experiment with a set of 10 representative valves, using the input capacity and band-width required for this experiment. The circuit was then taken as standard for the testing of the rest of the valves.

The input valve was shock-mounted on rubber. A high value of grid leak was chosen, to minimize grid current noise. Care was taken to keep the capacities to ground at the input grid as small as possible.

b. Sonde mounting

A sonde mounting was made so that the chamber could be used for the measurement of neutron distributions in aqueous solutions. In order to disturb such

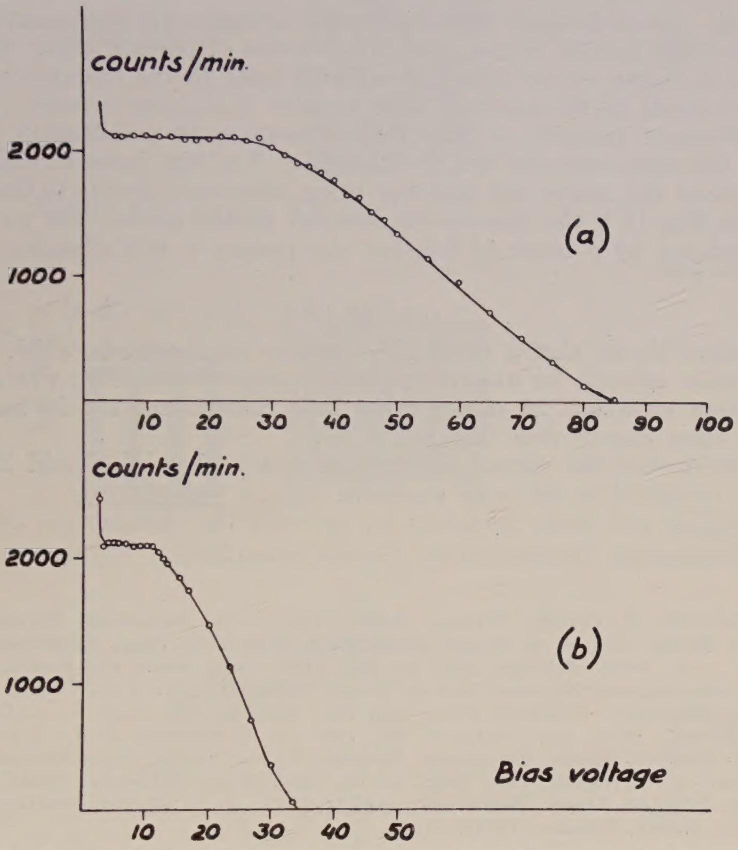

Fig. 13. Bias curves showing the effect of sonde capacities. Upper curve: chamber connected directly to amplifier. Lower curve: chamber mounted on sonde.

distributions as little as possible, the sonde must be slender, and must be constructed from materials having properties towards neutrons which do not differ too much from those of the surrounding medium. Also, the capacity between the central wire and ground must be kept low, to give a good signal-to-noise ratio.

One end of the sonde can be seen in Fig. 12. The outer casing is a brass tube 55 cm long, of 5 mm outside diameter and 0.5 mm wall thickness. Down the centre of this tube is stretched a 0.02 mm diameter tungsten wire, which carries the signals from chamber central electrode to the amplifier input grid. The space between the wire and the tube is filled with paraffin wax. The ends of the thin tungsten wire are joined to short lengths of 1 mm copper wire, which are mounted in perspex plugs forced into the ends of the brass tube. The central electrode of the chamber is soldered to one of these wires, and the space between the end of the sonde and the neck of the chamber is closed with a split perspex tube held in place with Araldite type 101, which also serves to waterproof the connection.

The high voltage lead at –850 volts runs through a 2.8 mm outside-diameter glass tube fixed parallel to the sonde by a series of perspex clips. The end of this tube is flared out to cover the soldered joint to the chamber outer electrode, and sealed to the chamber with Araldite.

The measured capacity of chamber and sonde is 18 pF. Fig. 13 shows the effect of the extra capacity due to the sonde. The bias curve of Fig. 13 a was taken without the sonde, the chamber being connected directly to the amplifier input. In Fig. 13 b the chamber is mounted on the sonde. The pulse amplitude is reduced by a factor of 2.5, but the plateau is still adequate.

V. SUMMARY

Calculation shows that a small BF_3 chamber can be made which will have characteristics suitable for absolute neutron measurements, even when it is used with electron collection. A chamber has been constructed, and its bias curve is found to agree closely with that calculated.

It is shown that the central electrode of such a chamber should be small in diameter, compared to its outer electrode.

An amplifier and sonde mounting for use with the chamber are described.

A.B. Atomenergi, Department of Physics, Stockholm.

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